Envelope materiality: light and heavy in wineries. The case of "Santa Ana" Winery, in Mendoza, Argentina.

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ABSTRACT

In a winery, energy flux exchange and thermal inertia of the envelope are crucial due to the constant need for stabilized temperatures. As a consequence, energy consuming systems like serpentine pipes inside tanks control temperature during fermentation; and air conditioned equipment maintains the appropriate microclimate in oak breeding barrels rooms. "Santa Ana" Winery, located in Mendoza (Argentina), presents two types of envelope materiality: one heavy (mainly adobe walls λ = 0.81W/mK) for fermentation and breeding stages and one light (mainly galvanized steel sheets λ = 45 W/mK) for the storage stage. In both cases the roof is insulated. A complete envelope analysis was made, data from auxiliary energy demand was collected and summer *in situ* temperature measurements were performed at critical control points. Also, recommendations to environmentally refurbish these envelopes are presented as a light/heavy equilibrium that could serve its purpose with a response from low energy architecture is needed.

Keywords: envelope materiality, energy consumption, winery.

1. INTRODUCTION

Primitive wineries were caves, that is, an emptiness found or made in the compact solid ground. When first on-the-ground wineries were built, the creation of the empty space in the most economical way many times neglected the full structure of thermal mass resistance, and the problem of interior temperature variations in wine production appeared.

In a winery there is a constant need of stabilized temperatures. A thermal abrupt change can put the whole process in jeopardy.

Physical elements of the environment, such as nature morphology and topographic aspects of the geographical site (orientation, urban structure, land topography, vegetation, sounds, noise and vibrations, contamination), and the climate (microclimate, solar radiation, wind intensity and direction, ventilation and illumination), account directly for site choice [for a winery], orientation, optimal form and materials to control solar protection and insulation materials. (1)

Optimal environmental conditions on different sites in wineries vary according to the needs of workers and the better settings for breeding and keeping wines. Temperature and humidity regimes are the principal environmental factors that need to be precisely controlled in the different sites of wineries.

In some spaces, illumination levels to be adequate to work and the total absence of estrange odors, have to be taken into account.(2)

Interior – exterior energy exchanges happen through the skin or envelope of the building that separates "interior" from "exterior".

The envelope is a dynamic border that interacts with external natural energies and internal building environment. It is also a fertile field to the development of layers and flexible control spaces that would facilitate the maintenance of stable temperatures within changing climatic characteristics.

In Mendoza, Argentina, first wineries were documented in the year 1600, buildings were simple and almost without measures of protection and conservation of grape fruits. Small and middle size spaces on the ground. It is supposed that grape juices exposed to temperatures over 25ºC corrupted rapidly and therefore, Mendoza's wines were of poor quality and easy alteration of initial properties. (3)

Nowadays, Mendoza produces one of the best D.O.C. *Malbec* varietal and is famous for its excellent wines. In order to provide the required environment to produce such an excellent product, mechanical energy consuming systems like serpentine pipes inside tanks controlled temperature during the fermentation process; and air conditioned equipment were installed in oak breeding barrels rooms.

Therefore, the purpose of this work is to evaluate the existent envelope and to make recommendations to achieve a light/heavy equilibrium of the envelope, that could serve its purpose with a response from low energy architecture.

2. WINERIES CLIMATIC NEEDS ON EACH PRODUCTION STAGE

2.1 Fermentation

Usually on metallic double-skinned tanks.

Temperature is more important in the containers than in the total dwelling. Between the double skin of the casks where fermentation is performed, tubes are placed, in which hot or cold water circulate depending of what is needed at the time.

As these casks have a superior opening, CO_2 generated by chemical reactions, that has a higher density than air, descend and accumulates in the inferior part. Therefore inferior ventilation is needed to renovate the air.

As light can also affect fermentation, therefore it has to be controlled in order to allow workers to perform their tasks attending to the wine production process.

2.2 Breeding

Usually on wooden (American or French oak) barrels and casks.

In this stage stability within the following reference ranges is very important:

- Air temperature between 12-16 ºC and relative humidity between 70-82 %.

- Air movement: To eliminate bad odors and other air volatile substances that can filtrate through wooden barrels.

- Minimal light. Only when it is absolutely needed.

2.3 Storage

Usually on glass bottles in cellars.

Of all stages, in this last one inside the building, stability is also a priority. To keep the four microclimatic parameters (temperature, humidity, illumination and ventilation) controlled is essential to obtain the expected result. At this moment the wine is bottled and it will not be moved until it is ready.

Very low illumination levels are here more important than in previous stages because the wine is bottled on glass that lets the light in, especially on the ultraviolet range of the spectrum, which can affect the most the final quality of the wine.

3. "SANTA ANA" WINERY

"Santa Ana" winery is situated in the North Oasis in the Province of Mendoza, Argentina, near the Andes Mountains (geographical coordinates: 32º52'South Latitude, 68º51'West Longitude, altitude 750 meters).

Mendoza has a continental dry-temperate climate with hot summers and cold winters. In summer, mean highest air temperature are between 35ºC and 40 ºC, and lowest mean temperatures vary between 18ºC and 22ºC. In winter mean minimum air temperatures are bellow 0ºC and mean maximum are between 10ºC and 15ºC.

Global Horizontal Radiation vary between 24000 and 25700 kJ/m^2 in summer, between 14000 and 22700 kJ/m^2 in autumn and spring and between 9000 and 11000 kJ/m^2 in winter. Annually average of Global Horizontal Radiation is approximate to 18000 kJ/m^2, been 700 W/m^2 as the highest power at solar noon.

Losses by long wave radiation are approximate to 180 W/m2. Mean daily temperature differences reach 10ºC to 18ºC.

3.1 Envelope materiality analyses

3.1.1 Materiality

"Santa Ana" Winery presents two types of envelope materiality: one heavy, mainly adobe walls berried 1 meter in the ground and tile roofs with wooden structure, a mixture of Spanish cane (*arundo donax*) and earth as insulation; and one light, with metallic structure and galvanized steel walls and roofs. Walls present a concrete slab base, only roofs are insulated with polyurethane foam.

The difference in the envelope materiality responds to the year of construction. The heavy envelope responds to the type of construction of the beginning of the 20^{th} century. The light envelope is being built nowadays, mainly for bottling and storage phases, as the winery`s production has increased and fermentation and breeding stages occupy the initial building. The choice of a light envelope responds to economical reasons as it is faster, cleaner and cheaper than the heavy traditional one.

This type of materiality for the new construction is chosen even though executive engineers know for a fact that the winery performs better with the heavy envelope.

Energy costs in Argentina are still very low (USD 0.15 per kWh) and therefore it is cheaper and easier to buy a new chiller for the new space than to built in the traditional way. That is why it is very important to propose solutions that attend the requirements of fast assembly with pre-produced materials.

Figures 1 and 2 show the two envelope alternatives. On figure 1 adobe walls have a white plaster finish and on roofs it is possible to appreciate Spanish canes and the wooden structure.

Windows are high and light is filtrated with green lattices. They can be open and therefore they consent high ventilation. (Even though the recommended ventilation for fermentation is that windows should be placed low in the space).

Figure 2 show new construction with galvanized steel walls and roofs. Light comes in through open doors and lanterns with fixed glass (ventilation is done by doors only, that are always open).

These lanterns are horizontal and do not present any kind of solar protection. That may present more light that required for storage phase. Moreover, notice the electrical lighting that is on at noon. To take these into account, bottles are usually kept in opaque boxes protected from light.

Fig. 1 and 2. From left to right, heavy old envelope and light new envelope.

Tables 1 and 2 present physical properties of the main materials of the envelope classified by walls and roofs, light and heavy. The U value, that depends of the particular thickness used in the building, is a very clear indicator of the great variety of energy flux exchanges that the envelope is going through in each space.

TABLE 1. Wall's materials properties

	HEAVY WALL		LIGHT WALL	
	Earth	Adobe	Galvanized Steel	Concrete Slabs
ρ = Density (Kg/m^3)	1800	1600	7850	2400
Cρ = Specific Heat (J/Kg.K)	1460	650	460	805
λ = Thermal Conductivity (W/m.K)	2.10	0.81	45	1.63
e = Thickness (m)	1	0.5	0.005	0.10
R = Thermal Resistance (m^2.K/W)	0.47	0.61	0.0001	0.06
U or Heat Transmittance (W/m^2.K)	2.12	1.63	10000	1.66

TABLE 2. Roof's materials properties

	HEAVY ROOF		LIGHT ROOF	
	Arundo donax / earth	Tiles	Galvanized Steel	Polyure thane Foam
ρ = Density (Kg/m^3)	75	1300	7850	49
Cρ = Specific Heat (J/Kg.K)	1000	840	460	1400
λ = Thermal Conductivity (W/m.K)	0.20	0.49	45	0.021
e = Thickness (m)	0.2	0.05	0.005	0.03
R = Thermal Resistance (m^2.K/W)	0.5	0.10	0.0001	1.42
U or Heat Transmittance (W/m^2.K)	2	10	10000	0.7

3.1.2 Interior – exterior heat flux exchange

In the heavy building of "Santa Ana" winery, 85% of the envelope is exposed to the exterior and therefore is located over the surface, and 15 % of the envelope is berried in the ground. This subterranean percentage responds to differences in the ground that where maintained and profited when the winery was built.

In the case of new construction, buildings are constructed over the ground surface. Figure 3 shows schemes of both cases. Also see Figure 10 for the building plan to compete the graphical information of ground and underground dimensions.

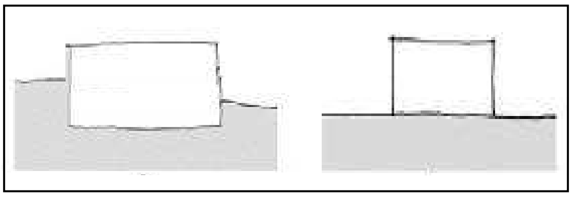

Fig.3. From left to right heavy and light building schemes

Possibilities of self-regulation are evaluated from the comparison of the heat flux of the two cases by using Fouriers Law Equation (Eq. 3).

$$Q = U * S * (Te – Ti) \qquad (3)$$

Where:
Q = flux (W)
U = heat transmission coefficient ($W/m^2.K$)
S = Envelope surface (m^2)
Te = Exterior temperature (K)
Ti = Interior temperature (K)

To calculate energy fluxes for the two types of space and compare their possibilities of self-climatic regulation, there will be established two fixed parameters:

S = Envelope surface = 100 m2
ΔT (Te – Ti) = 10 K

The following results were obtained. They show a tendency of the amount of energy flux that will be exchanged:

Heavy walls: Q = 1,630 W

Heavy roofs: Q = 2,000 W

Light walls: Q = 10,000,000 W

Light roofs: Q = 700 W

Notice that exchange values are similar in walls and roofs in the heavy envelope and very different in the light envelope. Insulation of the galvanized steel makes an important difference, as this value is also lower than the ones obtained in the heavy envelope.

For energy exchange analysis it is crucial that every element of the envelope is insulated no matter if its construction is heavy or light, traditional or pre-assambled.

Nevertheless, there will be important differences in these two envelopes when taking into account inertial benefits in a temperate continental climate with high variations between day and night and between seasons.

3.1.3 Thermal inertia

Thermal inertia calculus are performed with “Eduardo Torroja Institut Equations” (Eq. 1 and 2) using data provided in Tables 1 and 2.

$$I = R*S_{24} \qquad (1)$$

$$S_{24} = 8.48*10^{-3} * \sqrt{(\lambda*\rho *C\rho)} \qquad (2)$$

Where:
I = thermal inertia adimensional parameter
R = thermal resistivity (thickness “e” / λ) ($m^2.K/W$)
S_{24} = twenty four hour factor
$C\rho$ = specific heat at a constant pressure (J/ kg.K)
ρ = material density (kg/m^3)
λ = thermal conductivity (W/m.K)

Thermal inertia of the different materials that compose the heavy old envelope are:

- Walls:
Earth (1m thickness) I = 94.86
Adobe (0.50 m thickness) I = 38.91

- Roofs:
Arundo donax /earth (0.5 m thickness) I = 10.38
Tile (0.05 m thickness) I = 6.32

Thermal inertia of the different materials that compose the light new envelope are:

- Walls:
Concrete Slabs (0.10 m thickness) I = 9.23
Galvanized Steel (0.005 thickness) I = 0.12

- Roofs:
Polyurethane Foam (0.03 m thickness) I = 4.59
Galvanized Steel (0.005 thickness) I = 0.12

In this case, heavy envelope provides internal spaces with a crucial property: thermal stability. Light envelope does not have the same possibilities.

Up to this point there has been performed a complete envelope analysis using theoretical methods to evaluate the performance of “Santa Ana” winery. The next step is to perform in situ temperature measurements.

4. DETERMINATION OF CRITICAL CONTROL POINTS

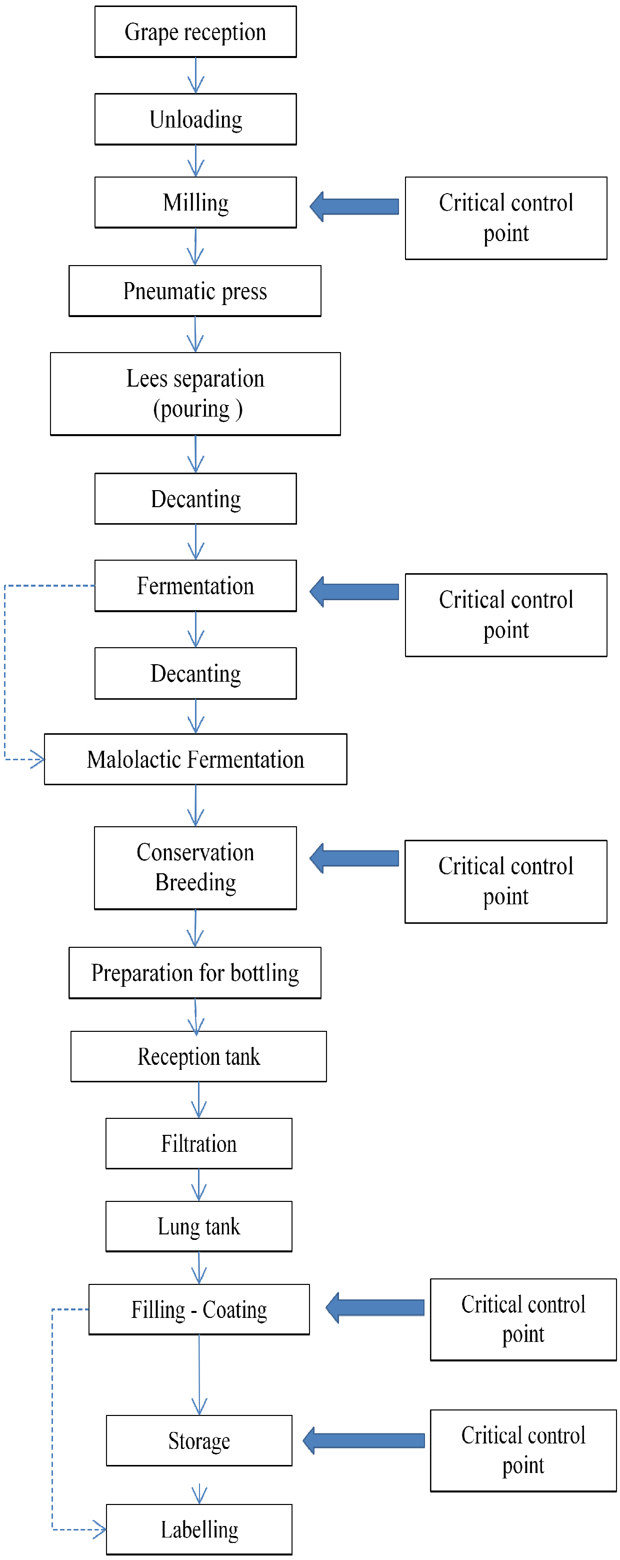

Fig. 4. Flux diagram of the industrial process. Detection of environmental and energetic critical control points.

Fig. 5 Critical control point 1 – Milling / Press

Fig. 6 Critical control point 2 and 3. Fermentation

Fig. 7 Critical control point 3. Breeding

Fig. 8 Critical control point 4. Bottling.

Fig. 9 Critical control point 5. Storage.

Hazard Analysis and Critical Control Points (HACCP) (4) (5) food safety methodology was adapted *ad hoc* to specific environmental and energetic issues concerning wine production.

The winery has already certified the following food harmlessness policies: IRAM BMP (Manufacture good practices), HACCP (Hazard Analysis and Critical Control Points) and BRC (highest level): British Retail Consortium Standard Approval.

Therefore, HACCP methodology was already known and accepted by the management of the winery and it was possible to adapt it to environmental and energetic purposes. Consequently, in this study critical control points determine the specific moments in which temperature is essential to the final quality of wine.

Environmental and energetic critical control points where detected through a flux diagram in the industrial process. (See Fig. 4). In Fig. 5 to 9 photographs of the architectural spaces related to critical control points are presented.

5. <u>SUMMER IN SITU TEMPERATURE MEASUREMENTS</u>

Temperature measurements were performed following the six identified critical control points. A seventh measure was taken in the exterior in order to evaluate the envelope performance.

To perform *in situ* temperature measurements, the *Walkabout* methodology proposed by Guerra (6) was used. This method is adapted to field trips in which it is difficult to set data loggers for a long period of time. It consists mainly in taking several measurements of each space in a short period of time.

For air temperature measurements an ONSET HOBO U14-001 data logger was used. It was programmed to take a measurement every 15 seconds in order to register air temperature while walking through the different spaces of the winery.

Measurements where performed on January 13th, 20th, and 27th (summer in the South Hemisphere) at solar noon and the complete field trip took an hour.

Management of data loggers followed the recommendations of Longobardi and Hancock (7) for an efficient use of these instruments.

Figure 10 shows a plan of the winery in which the six architectural spaces related to each critical control point are identified. Table 3 complements this graphical information with the indication of the production process involved in each critical control point associated to mean measurement results.

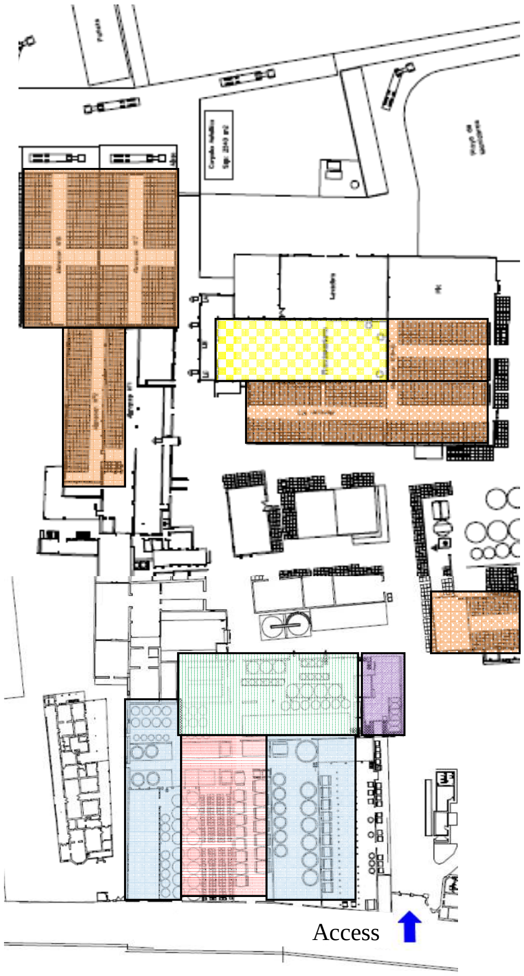

Fig. 10. “Santa Ana” winery plan.

<u>TABLE 3</u>. References to Fig. 10 and measured mean air temperature on each critical control point.

“Santa Ana” Winery Measured critical control points	Mean Air Temperature
Milling / Pneumatic press	31.5 ºC
Fermentation – Metallic Tanks	25 ºC
Breeding – Oak Barrels	25 ºC
Breeding – Metallic Tanks	26.5 ºC
Bottling (filling/coating)	32 ºC
Storage	30 ºC
Exterior	35 ºC

6. AUXILIARY ENERGY REQUIREMENTS

Grapes arrive at a mean temperature of 26ºC, that temperature has to drop to 8ºC after undergoing the press and the first cooling serpentine. Subsequently, in metallic double-skinned tanks juices' temperature has to be stabilized at -5ºC. If we take into account that measured air temperature in the press is usually over 33ºC and 25ºC in the location of metallic double-skinned tanks, the ΔT is 25ºC in the first case and 30ºC in the second case. These temperature differences make the use of chillers so intensive, and therefore the use of auxiliary energy.

"Santa Ana" winery has tree chillers: one of 500.000 B.T.U./hour, and two of 300.000 B.T.U/hour, for a total of 1.100.00 B.T.U/hour.

All year long 500.000 B.T.U./hour (1 chiller) are used for breeding and bottling. Four months a year, during fermentation, the amount of B.T.U/hour increases to 1.100.000 (3 chillers) to stabilize the fermentation process of 1.500.000 of liters.

7. RESULT DISCUSSION

Heavy old envelope keeps temperatures 8.5ºC to 10ºC bellow outside measurements; while spaces with light new envelopes are only 3ºC to 5ºC below outside temperatures.

These results are coherent with the inertia of the envelope materials. The heavy old walls' inertia coefficient was calculated between 38 and 95, while light new walls have an inertia coefficient of 0.22 to 10.

Nevertheless, neither resolve completely wine production needs of climatic regulation as air temperature needs to be between 12ºC to 16ºC. Steel 10ºC bellow the best measured temperature! This is the cause of the excessive energetic consumption of 8.400.000 B.T.U/hour per year.

If the winery was underground the inertia coefficient would be around 100 for all walls and roofs. That is the main reason why it is always preferable to have the critical moments of the process, especially those that take a long time such as barrel breeding, in an underground level to save cooling energy and assure all year long stable temperatures
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8. ENVIRONMENTAL REFURBISHMENT RECOMMENDATIONS

As it is almost impossible to change the level of a built winery, environmental and energetic recommendations must be orientated to better the existent envelope of this building, that will continue functioning for many years ahead. The concern of considering existing buildings as research objects follows Kohler and Hassler theories (8).

On heavy old envelope construction, the recommendation is to diminish undesired infiltration by windows and doors, as they are made from old wood and leave important renovations per hour. Renovation may be efficient and flexible enough so management can adapt them to specific production needs, for example to ventilate CO_2 during fermentation.

In what respects new construction, it must be fast and cheap to attend management needs and resources but it is very important that an equilibrium between light and heavy envelope is accomplished, particularly in temperate, very variable climates such as Mendoza's. For this, it is strongly recommended to continue building the concrete base, and if it is possible to make it wider and longer. The light galvanized iron walls must be insulated as the roof. The heavy base will provide the needed inertia and the insulated walls will reduce energy flux exchanges.

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